
LACTOSE

review of its properties and uses in bakery products

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Lactose, or milk sugar, with few exceptions, is by far the chief carbohydrate of mammal's milk. Next to water, lactose occurs in the highest concentration in fluid cow's whole milk, skimmilk, buttermilk, and cheese wheys. **Table I** shows an analysis of dried milk products, which are the forms of milk or milk products normally used by the baker. Note that dried milk products contain anywhere from 36 to 74 per cent lactose. In spite of the fact that lactose makes up a sizable percentage of the dried milk products, the functional and value-improving properties of these powders, with the exception of browning, are generally ascribed to their protein, fat and mineral contents. To some extent its role in baking is not fully recognized or dispensed with as of small consequence. It is the purpose of this paper to describe the chemical, physical, and nutritive properties of lactose that are of interest to the baker. The methods pertaining to its production will also be described. Lastly, the functional and value-improving prop-

erties of lactose as a bakery ingredient will be reviewed.

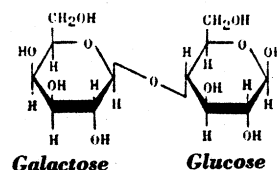
Surplus cheese wheys, both sweet and Cottage cheese, are a source of commercial lactose. In 1969, 93 million pounds (1) of lactose were produced. This amount represents only 8 per cent of the potential lactose supply derivable from cheese wheys. Since two-thirds of cheese wheys are not used for feed or food, the further utilization of lactose from this source would be highly desirable. This utilization would help alleviate the pollution problems caused by disposing of excess wheys, much of which is dumped into lakes and streams. Stiffening federal, state and local laws makes utilization of whey and whey constituents almost mandatory, or that the material be disposed of without contributing to air or water pollution.

Chemical and Physical Characteristics

When adding lactose to baked products, it is well to bear in mind the following discussion relating to the physical and chemical properties of this sugar. Its reducing capacity, sweetness, solubility, and structural

forms all influence its utilization.

Structure. Lactose is a reducing disaccharide that yields D-glucose and D-galactose on hydrolysis. The two monosaccharides are linked between the number one or aldehyde-containing carbon atom of D-galactose with the number four carbon atom of D-glucose. D-galactose is present in the beta configuration. The aldehyde group of D-glucose is free to act in a reducing capacity. The Haworth formula for alpha lactose may be depicted as follows:



Because lactose is a reducing sugar, its amount can be determined by measuring its reduction of substances such as picric acid (2), and copper sulfate (Fehling's Reagent) (3). Bakers' yeast will not hydrolyze or ferment lactose but will invert or hydrolyze sucrose and thus form reducing monosaccharides which can be fermented. Advantage is taken of this fact to determine lactose in baked products (4). First, an extract of the reducing monosaccharides present, and those produced by enzymatic cleavage of starch, are fermented by bakers' yeast. The residual lactose is then determined colorimetrically. Since nonfat dry milk contains about 50 per cent lactose, the percentage milk solids is obtained by multiplying

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Table I
Typical Analysis of Dried Milk Products

| | % Lactose | % Protein | % Ash | % Moisture |
|---------------------|-----------|-----------|-------|------------|
| Sweet whey | 73.0 | 12.5 | 8.4 | 2.7 |
| Cottage cheese whey | 66.4 | 12.0 | 8.6 | 3.5 |
| Nonfat dry milk | 51.0 | 36.5 | 7.5 | 3.0 |
| Buttermilk | 48.0 | 36.0 | 7.8 | 3.5 |
| Whole milk | 36.5 | 26.2 | 6.1 | 2.5 |

the per cent lactose by two.

Crystal Forms. Lactose normally exists either as the alpha-hydrate or beta-anhydride form or as an amorphous "glass" mixture of alpha and beta forms (5). Commercial lactose contains one water molecule in its crystal ($C_{12}H_{22}O_{11} \cdot H_2O$). It is known as alpha-lactose monohydrate or alpha-hydrate. This form crystallizes out of aqueous super-saturated solutions below 93.5°C (200.3°F). It is considered to be the stable solid form because other solid forms change to the hydrate in the presence of a small amount of water below 93.5°C (200.3°F). The usual forms, prism and tomahawk shaped crystals, melt at 201.6°C (394.8°F). When placed in the mouth, they feel hard and gritty and cause the defect called sandiness in ice cream. This defect depends upon the size as well as the number of crystals. Crystals below 10 μ size cannot be detected but above 16 μ they can.

Beta anhydride crystallizes out of solutions at temperatures at or above 93.5°C (200.3°F). The even-sided diamond crystals of m.p. 252.2°C (486°F). are initially sweeter and considerably more soluble than alpha hydrate crystals.

Lactose glass is the form commonly found in spray-dried milk. Due to the fast drying and low moisture of the powder, lactose is prevented from crystallizing. The reason milk powder picks up moisture rapidly, and thus necessitates storage in sealed containers, is that the lactose glass is very hygroscopic. The glass consists of an equilibrium mixture of beta/alpha forms in the ratio of 1.68 at 20°C (68°F). The alpha form rotates polarized light in the dextro or clockwise direction. The beta form rotates polarized light in the levo or counter-clockwise direction.

An alpha anhydride can be produced by heating the alpha hydrate at 100°C (212°F) in vacuo. The rate of the reaction can be increased by heating at 120-125°C (248-257°F). The product is very hygroscopic and will form the hydrate very readily unless kept in a hermetically sealed container. It has a melting point of 222.8°C (433.0°F).

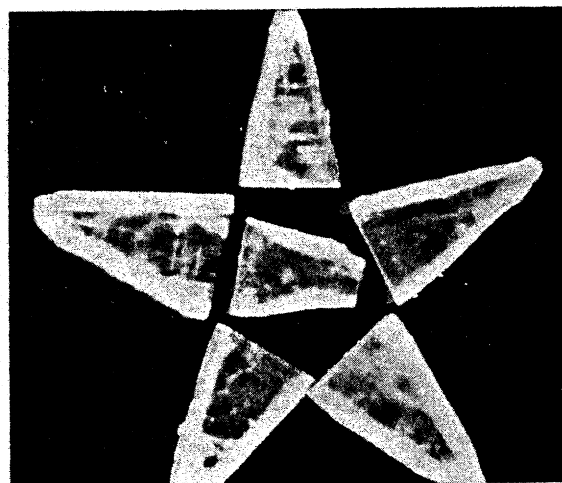
Solubility. Relative to cane sugar, lactose has poor solubility (6). **Table II** shows the final solubilities in water of sucrose and lactose at different temperatures. The alpha hydrate form has less initial solubility than the beta anhydride. Each sugar in solution mutarotates to a fixed ratio of alpha to beta at any one particular temperature.

The solubility of lactose is altered by other salts (7) and sugars. Calci-

um salts are known to increase its solubility. Alcohol decreases the solubility of the crystals but increases that of the glass or amorphous powder.

Sweetness. Lactose is not a sweet sugar relative to many others (5). However, the relative sweetness of sugars changes with concentration. Many tables do not show this fact. Lactose is relatively sweeter at higher than lower concentrations. About 3.5 per cent lactose is required to give a sweetness equivalent to a 1 per cent sucrose solution, while a 13 to 16 per cent concentration of lactose is equivalent in sweetness to 5 per cent sucrose. A 21 to 26 per cent lactose solution is equivalent to a 10 per cent sucrose solution. These values for sweetness are greater than generally reported in the literature: *i.e.*, that lactose is one sixth as sweet as sugar. The beta form is also sweeter than the alpha hydrate form but, on standing in solution, either can mutarotate to change to an equilibrium mixture whose sweetness is dependent upon the concentration and equilibrium ratio.

Manufacture. Prior to World War II lactose was made predominantly from hydrochloric acid-treated whey obtained from the manufacture of casein (5). The chief source of lactose is sweet whey. Sweet fluid whey contains about 5 per cent lactose, 0.9 to 1.0 per cent protein and 0.5 per cent



Characteristic forms of micro-crystals of lactose.

ash. The purity of the lactose is determined by the degree to which these proteins and salts are removed prior to crystallization. Protein and salt removal is controlled by adjusting the pH, by use of heat, enzymes and tetraphosphates.

To manufacture alpha lactose monohydrate, whey is limed, heated and filtered to remove the proteins and calcium phosphate. The whey is concentrated to 30 per cent solids and refiltered to remove any protein and salts that separate on concentration. The whey is further concentrated and then crystallization is induced. The greater the concentration, the greater the yield, but if the concentration is too great, the crystals coalesce and make removal of impurities more difficult. Perforated basket centrifuges revolving at high speed separate the crystals from the mother liquor. The crystals are then sprayed with fresh water to remove the adhering liquor. The crystals may be dissolved again in water and treated with activated carbon to decolorize the solution. This produces a USP grade of lactose, assaying 99.85 per cent lactose hydrate and 0.1 per cent moisture. This is the purest grade suitable for fine chemical use. An edible grade of 99.0 per cent purity, costing less than USP grade, may be used by the baker. Crude crystals are also made of 98.4 per cent purity, selling for considerably less than the price of the USP grade.

Weisberg (8) has described a number of applications of ion exchange to lactose production. In these applications, anionic and cationic exchange resins are used to remove impurities from the solution.

Almy and Hull (9) treated whey with sodium tetraphosphate. This prevents heat coagulation of the protein. Then, after suitable condensing, the lactose can be separated by crystallization from concentrated whey.

Beta lactose is produced to some

Table II
Solubility in g/100 g Water

| Temperature °C | Lactose | Sucrose |
|----------------|---------|---------|
| 0 | 11.9 | 179.2 |
| 15 | 16.9 | 197 |
| 25 | 21.6 | 211.4 |
| 39 | 31.5 | — |
| 40 | — | 238.1 |
| 79 | 98.4 | — |
| 80 | — | 362.1 |
| 100 | 157.6 | 487.2 |

extent because this sugar has higher initial solubility and is sweeter than alpha lactose. In one process (10) a lactose solution in the form of a film is dried on a heated surface above 100° C (212°F). The film is removed as a paste at 2 per cent moisture and the lactose crystallizes. The remaining residual heat in the paste completes the drying. Beta lactose is also crystallized from a saturated solution of lactose by adding alpha lactose to the solution and holding above a temperature of 93.5°C (200.3°F). Since equilibrium between the two forms is established rapidly at this temperature, the alpha dissolves and the beta crystals quickly form. Then, by using a heated centrifuge to recover the crystals, a sugar that is high in beta lactose is obtained.

Nutritional value. Lately it has been shown that certain adult Oriental (11) and Negro (12) groups are intolerant to the ingestion of lactose. Generally, these subjects become intolerant to lactose after ingesting relatively sizable amounts of 25-50 grams of the sugar, equivalent to the lactose in one pint to one quart of milk. Experiments with lactose feeding by Riggs and Beaty (13) show that a diet containing in excess of 25 to 30 per cent of lactose has an adverse effect on food utilization and growth for the young rat. Thus, the thing to avoid with lactose is high levels in the diet. It is estimated that an entire cake with 10 per cent added lactose on a flour basis would contain only about 5 g lactose, or less than 0.5 gm per piece. Likewise, a slice of bread with a 6 per cent level of nonfat dry milk on a flour basis would contain less than 0.5 g lactose.

In a review, Atkinson *et al.* (14) stress some of the nutritional effects of lactose: (a) It favorably influences the absorption, retention and utilization of calcium, phosphorus, and magnesium. (b) It is the sugar of choice for infant formulae. By adding it to cow's milk, a formula is obtained which more nearly simulates mothers' milk with its reduced protein and salt and increased lactose levels. (c) With the proper kind and level of fat in the diet, the utilization of lactose is improved. Boutwell *et al.* (15) reported rats showed superior growth on butter fat compared to corn oil when lactose was the sole source of carbohydrate. (d) Galactose in milk sugar is considered to be the structural sugar necessary for development of brain and nerve tissue. (e) Lactose stimulates the synthesis of B vitamins by the intestinal bacteria in animals. Lactose is also known to be tolerated by diabetics. Many diabetic ice creams contain substantial quantities of it.

Use and Function in Bakery Products

Lactose modifies the functional characteristics of bakery products and doughs by performing in the following ways.

Browning. Because lactose is not hydrolyzed and fermented by bakers' yeast, or modified in chemically leavened batters, it is fully available for browning in bakery products. Under the influence of oven heat the free aldehyde group of the sugar and amino groups of proteins interact in the crust to form golden brown or dark-colored melanoidins. The reaction is accelerated by an increase of pH or alkalinity and decreased by lowering the pH. This can easily be seen in cakes containing nonfat dry milk in which the pH has been modified by the addition of acids or alkalies. Work of this laboratory shows that lactose alone does not produce the intensity of browning in baked goods that an equal amount of lactose in whey or nonfat dry milk does, presumably because the protein of the milk enters into the browning reaction. However, the addition of lactose alone will greatly increase browning by virtue of its interaction with flour or egg protein. This has been observed in our laboratories (16) with yellow layer cakes.

Tenderizing. Lactose functions, as do other sugars, in promoting tenderness of baked products. De Goumois and Henning (17) showed that the addition of 30 per cent extra sugar as sucrose, alpha or beta lactose, or glucose to 100 per cent ratio sugar cakes produced cakes of increased volume, texture and tenderness scores. The cake with beta lactose had highest volume and remained the most compressible. An added 15 per cent sugar produced similar but less pronounced effects than added 30 per cent sugar. Thus, it is possible to substitute lactose for some of the sucrose when not quite as sweet a cake is desired, but one of equal tenderness and total score. However, compared to 15 per cent lactose, cakes with 20 per cent sweet whey did not have as high a volume, but were more compressible and tender.

Potter and Zaehring (18) have shown that addition of lactose to baking powder biscuits containing nonfat dry milk maintains or increases their volume, significantly increases their tenderness, and produces a whiter biscuit. As judged by the panel, lactose biscuits were more flavorful than control biscuits. Of interest in this study was the fact that increases in tenderness of lactose-containing biscuits could not be ascribed to moisture differences of the products.

Hoffstrand, Zaehring and Hibbs (19) showed that addition of lactose to doughnuts containing buttermilk solids produced products of increased tenderness and significantly more compressible crumb with no change of volume. Taste panel data indicated lactose doughnuts were preferred more often than the whey-containing and control products.

Reger (20) reported that pie doughs with 8 per cent lactose (flour basis) are more tender and shorter after both mixing and baking. They sheet out better and then shrink less before and after baking. The crust is less soggy, and tolerance to mixing is greater. In rotary cut cookies, 3 to 4 per cent lactose causes the dough to release more readily from the dies, and allows cookies to maintain their shape during baking.

Sweetness Reduction. Since lactose has as little as one-sixth the sweetness of sugar, it can be substituted for part of sucrose, providing the solubility limits of the sugar are not exceeded. Reger (20) reports that whenever a reduction of sweetness is desired, with some accentuation of flavor, lactose can be substituted for cane or beet sugar. Icings and pie fillings are examples of this. When 15-20 per cent of the sugar is replaced by lactose, custards and cream fillings of pies become smoother, more tender and richer tasting. In cakes, replacement of up to 30 per cent sugar (flour basis) with lactose tends to decrease sweetness with no loss of quality.

Flavor Enhancement. The presence of lactose in foods favors the accentuation and maintenance of flavor. This is especially true of acid type fruit-flavored foods which may be used as fillings in baked foods. Weiss (21) reports that in the preparation of fruit conserves, replacing one-third of the sugar with lactose gives superior flavor. However, after six months, crystallization of lactose gives the product a gritty texture. This could probably be controlled by seeding the product with finely divided lactose. Mention was previously made that lactose-made biscuits were more flavorful (18). Also, doughnuts containing it were preferred over products containing other milk and milk by-product ingredients (19).

Other properties which lactose shows when used in baking ingredients are as follows:

Preservation. Dawson and Wood (22) have shown that lactose improved both the baking and keeping quality of spray dried whole eggs. At 100°F, 10 per cent lactose maintained eggs of good quality for eight weeks. In contrast, the control eggs retained

Table III
Effect of Variations in Bread Formulation on Bread Quality of
of Lactose-Containing Mixes

| Treatment | Bread Characteristics | | | | | | | Total Score |
|----------------|-----------------------|-------------|----------|---------------|-------|-------------|---------|-------------|
| | Loaf Score | Crust Color | Symmetry | Break & Shred | Grain | Crumb Color | Texture | |
| 1. Control | 18 | 4 | 8 | 9 | 15 | 9 | 15 | 78 |
| 3. 5% Sucrose | | | | | | | | |
| 4% Dry milk | 19 | 9 | 9 | 7 | 19 | 10 | 18 | 91 |
| 4. 5% Lactose | 17 | 7 | 6 | 5 | 16 | 10 | 14 | 75 |
| 5. 5% Lactose | | | | | | | | |
| 0.25% FLA* | 18 | 9 | 9 | 9 | 18 | 9 | 17 | 89 |
| 9. 4% Dry whey | | | | | | | | |
| 0.25% FLA* | 19 | 9 | 9 | 9 | 18 | 9 | 17 | 90 |

*FLA = fungal lactase A.

good baking qualities for only one week.

Lactose will preserve non-lactose fermenting yeasts very well. About 10 to 20 per cent lactose added to yeast solutions preserved them up to six months. When added to a suitable medium, such as molasses, yeast begins fermenting with a minimum lag period (23).

Whipping. Patents have been issued for whipped topping formulations containing lactose. A whipping agent for cakes, pies, and meringues, producing better emulsification and blending with flour and sugar, contains sodium caseinate, lactose, and hexametaphosphate (24). Kozlick and Swanson (25) have patented a whipable topping for cake which contains lactose.

Commercial toppings can be found in the supermarket which contain added lactose as well as whey. It is thought the lactose may function in accentuating any fruit flavors in products with which topping may be used.

Mickevic *et al.* (26) report that in certain types of aerated icings containing soy protein, lactose aids in improving stability and plasticity attributes that are desirable in freezing and thawing.

Volume Modification. Larson *et al.* (27) originally showed by the straight dough pup-procedure that lactose decreased the volume of bread. The decrease is overcome to some extent by addition of potassium bromate. No suggestion for the mechanism was advanced. In a later investigation of this action in sponge breads, Guy *et al.* (28) came to the conclusion that the action of lactose in suppressing volume was due to osmotic effects, similar to those produced by additional formula sugar (sucrose). However, at the normal or 7.5 per cent level of sugar in the formula, additional sucrose suppressed CO₂ production and increased proof time more than did an equal amount of added lactose. This is presumably

because additional sucrose is hydrolyzed by yeast, thereby doubling its molar concentration, and increasing its effective osmotic pressure. The small to moderate volume decrease, depending upon the amount of lactose used, can be minimized by substitution of dry for compressed yeast, use of lower levels of formula sugar, proofing doughs to height instead of time, and use of lower levels of salt and higher levels of yeast. Because the lactose-containing dry milk and whey powders respond to these modifications in a like manner at equivalent lactose levels, it was concluded that the lactose of these products plays a significant role in their volume depressing action.

Effect on Starch Gelatinization. Hirai *et al.* (29) have shown that lactose increases starch paste viscosities and volume of starch granules in both starch and starch-shortening pastes. The mode of action of lactose in the paste is not known. Also, the presence of lactose delayed the attainment of maximum viscosity. Hester *et al.* (30) also showed that sucrose delayed the swelling of starch.

Pigment Absorption. Lactose is superior to other sugars in absorbing pigments. Coupled with the fact that it does not go into solution as rapidly as other sugars, this means it has the ability to gradually release dyes into an aqueous sugar system more slowly and uniformly. Thus no concentrated droplets are formed. These features are important to manufacturers of colored puff pastry and colored icings (20) used in baked products.

Use of Hydrolyzed Lactose in Bread

Of interest is a paper by Pomeranz *et al.* (31) in which lactase enzyme was used to hydrolyze the lactose of milk products as a source of fermentable glucose in straight doughs. Since lactose yields equal amounts of both

glucose and galactose, one half of added lactose, when split, can function as a fermentable sugar. The authors stated that milk is used in many countries in bread in which no sugar is employed in the formula and consequently, a compact loaf is produced. Lactase, if added, should hydrolyze the lactose, produce fermentable glucose, and raise bread volume. Their studies indicated that adding 5-12 per cent lactase based on the weight of the lactose as the sole source of carbohydrate results in a much more acceptable loaf of bread made with malted flour. Surprisingly, the total score of bread to which 5 per cent lactose plus lactase, or 4 per cent dry whey plus lactase were added, approached very close to that of a bread with 5 per cent sucrose and 4 per cent nonfat dry milk. (Table III). The authors stated that since lactase activity is higher at temperatures of 40-45°C (104-113°F) than at temperatures employed in panary fermentation, optimal conditions were probably not obtained. The authors also stated that as the rate of hydrolysis is slow, adding hydrolyzed nonfat milk powder, or using lactase in preferments rather than adding lactose to the dough, might be more advantageous.

Use of Whey vs. Lactose

One of the shortcomings of lactose, especially of the purified USP and edible grades is its high cost. It is anticipated that finding markets for the protein portions of whey would lead to a decrease in the cost of lactose. However, the advantage of using lactose in a baked product vs. the use of cheaper whey solids containing better than 70 per cent lactose has to be considered.

Although many of the attributes of lactose apparently carry through into the properties of whey, there are functional differences between the two. Although the differences are small, doughnuts with lactose were more compressible and absorbed more fat than those made with sweet whey (19). Lactose-containing doughnuts were most often preferred. With biscuits lactose produced a whiter crumb (18). The crust of whey biscuits was significantly crisper than those containing lactose. Interestingly enough, though, the tenderness and moisture-absorbing characteristics of products containing mixtures of whey protein and lactose are much closer to those of products containing added whey proteins or to control biscuits than to products containing sweet whey solids. Thus, the salts of whey, or combinations of them with other ingredients, are implicated in the tenderizing effects of sweet whey. De Goumois

and Hanning (17) also show that a more compressible and tender cake of smaller volume is obtained with 20 per cent whey than with 15 per cent lactose. The results of this laboratory also support the above observation that whey products make a more compressible cake than does lactose.

Conclusion

It is anticipated that the use of lactose will grow as scientists develop new products and improve existing ones. Furthermore, creating markets for whey protein concentrates, currently being developed, might reduce the cost of lactose.

Its unique properties of solubility, low sweetness, flavor enhancement, browning and tenderizing, offer opportunities for food technologists to capitalize on this sugar in their food products. A very recent publication has just reported on the development of low-cost dairy-like cream cheese substitutes for bakery use (32). The novel product contains both lactose and whey solids for body and flavor building, in combination with vegetable fat, emulsifiers, stabilizers, corn syrup solids and flavoring agents.

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